Presented at the 17th Masurian Summer School on Nuclear Physics, Mikołajki, Poland, September 1985; and to be published in the Proceedings

NEW DROPLET MODEL DEVELOPMENTS

C.O. Dorso, W.D. Myers, W.J. Swiatecki, P. Möller, J. Treiner, and M.S. Weiss

September 1985
DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or the Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or the Regents of the University of California.
New Droplet Model Developments

C.O. Dorso,† W.D. Myers and W.J. Swiatecki

Nuclear Science Division
Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

P. Möller‡

Nuclear Theory, T-9
LASL MS 452
Los Alamos, New Mexico 87544

J. Treiner

IPN n° 1
97406 ORSAY Cedex
France

M.S. Weiss

Nuclear Physics Division
Lawrence Livermore Laboratory
University of California
Livermore, California 94550

To be published in the Proceedings of the 17th Masurian Summer School on Nuclear Physics, Mikolajki, Poland, September 1985.

This work was supported in part by the Director, Office of Energy Research, Division of Nuclear Physics of the Office of High Energy and Nuclear Physics of the U.S. Department of Energy under Contract DE-AC03-76SF00098.

†Permanent address: Departamento de Fisica, Facultad de Ciencias Exactas y Naturales, universidad de Buenos Aires, 1428 Buenos Aires, Argentina

‡Permanent address: Department of Mathematical Physics, Box 725 S-22007 Lund, Sweden
A brief summary is given of three recent contributions to the development of the Droplet Model. The first concerns the electric dipole moment induced in octupole deformed nuclei by the Coulomb redistribution\(^1\). The second concerns a study of squeezing in nuclei\(^2\) and the third is a study of the improved predictive power of the model when an empirical "exponential" term is included\(^3\).

\(^*\)This work was supported in part by the Director, Office of Energy Research, Division of Nuclear Physics of the Office of High Energy and Nuclear Physics of the U.S. Department of Energy under Contract DE-AC03-76SF00098.
1. INTRODUCTION

Of the three recent papers describing Droplet Model developments that are discussed here, the first, "Droplet Model Electric Dipole Moments"\(^1\), is simply a straightforward application of the standard approach. In this work the electric dipole moment that is induced in octupole deformed nuclei by the Coulomb repulsion of the protons is calculated in two parts. The first part is a purely volume effect, which had been considered earlier in the framework of the Liquid Drop Model\(^4,5\), and the second part is associated with the neutron skin, which is a new Droplet Model degree of freedom.

The second paper, "Bulk Compression Due to Surface Tension in Hartree-Fock, Thomas-Fermi and Droplet Model Calculations"\(^2\), began as an inquiry into certain discrepancies that other authors had found between Hartree-Fock calculations and Droplet Model predictions\(^6,7\). The comparisons that were undertaken brought our attention to terms in the expressions for the central density (and binding energy) of a nucleus that are outside of the original formulation of the Droplet Model. The importance of these "exponential" terms is discussed and an empirical term of this type is proposed for inclusion in a Droplet Model type of nuclear mass formula.

The third paper, "Finite Range Droplet Model"\(^3\), incorporates both "finite range" terms from an earlier work\(^8\) and the "exponential" terms mentioned above into a Droplet Model mass formula\(^9\). Excellent results are obtained and these are discussed in some detail.
2. DIPOLE MOMENTS

In two recent papers Leander has examined a number of experiments on isotopes in the Ra-Th region indicating unusually fast E1 transitions. These transitions appear to be collective and associated with ground-state electric dipole moments. Indeed, it was noted earlier that the Coulomb repulsion of the protons can induce such moments in deformed nuclei that have odd-parity components in their intrinsic deformation in addition to the usual even-parity components.

Both theory and experiment support the presence of octupole-deformed intrinsic equilibrium shapes in this region of nuclei, and Leander has made pioneering attempts to estimate what fraction of the observed electric dipole moment might be associated with the particular orbital configurations occupied in each nucleus (representing the microscopic or shell effects) and what fraction might be due to the octupole-induced polarization of the bulk nuclear matter (corresponding to a macroscopic or Liquid Drop Model effect).

A guiding theme of the Droplet Model is that the requirement to work consistently to a definite order in the relevant expansion parameters makes it necessary to include two new sets of degrees of freedom specifying the nuclear configuration: the nucleon density non-uniformities and the neutron skin. The inclusion of the former leads to a redistribution of the proton and neutron densities under the influence of the electrostatic forces, and this induces a slight dipole moment in deformed, reflection asymmetric nuclei. This is the effect that had been studied already.
in the early papers of Strutinsky\textsuperscript{4} and Bohr and Mottelson\textsuperscript{5} in connection with the dipole moment and in refs. 14-16 in connection with fission. The inclusion of the neutron skin degree of freedom also leads to a slight separation of the centers of mass of the neutrons and protons, resulting in another contribution to the dipole moment. This influence of the neutron skin on the dipole moment does not appear to have been studied before. As we shall see, the effect is, in most cases of interest, of a magnitude comparable with the charge-redistribution effect (and of opposite sign!). This means that a meaningful estimate of the macroscopic part of the nuclear dipole moment cannot be made without taking into account the neutron skin contribution in addition to the charge redistribution effect.

We find that the dipole moment (in units of the proton charge $e$) is given by the following expression:

$$d = C_r \sum_{\ell=2}^{\infty} \frac{12(\ell - 1)(\ell + 1)(8\ell + 9)}{5(2\ell + 1)^2(2\ell + 3)^2} \alpha_{\ell} \alpha_{\ell+1}$$

$$- C_s \sum_{\ell=2}^{\infty} \frac{(\ell - 1)(\ell + 1)(\ell + 3)}{(2\ell + 1)(2\ell + 3)} \alpha_{\ell} \alpha_{\ell+1}$$

$$+ \text{terms of higher order in the } \alpha_{\ell} \text{'s } \quad (1)$$

Here $\alpha_{\ell}$ are the coefficients specifying the usual Legendre Polynomial expansion of the radius vector $R(\theta)$, describing the surface $\Sigma$ according to

$$R(\theta) = R_0 \left[ 1 + \sum_{\ell=2}^{\infty} \alpha_{\ell} P_{\ell}(\cos \theta) \right] \quad (2)$$
NEW DROPLET MODEL DEVELOPMENTS

The coefficients $C_r$ and $C_s$ are definite functions, given below, of the neutron and proton numbers $N,Z$ and of the equivalent radius $R_0$ of the nucleus in question, as well as of the relevant parameters specifying the volume energy per particle and the surface tension coefficient in the Droplet Model. The first term in eq.(1) describes essentially the "lightning rod" effect, according to which the electric charge, when allowed to redistribute itself, tends to move towards regions of the surface with large curvature. The second term describes the neutron skin effect according to which, even in the absence of any non-uniformities either in the densities $n,p$ or the neutron skin thickness $t$, a dipole moment may appear (for non-zero $t$) because of the geometrical fact that the center of gravity of a uniform thin neutron layer around the surface $\Sigma$ does not coincide, in general, with the center of gravity of the volume enclosed by $\Sigma$.

The estimates of the dipole moment according to ref. 4, in which the neutron skin contribution is disregarded and the redistribution effect is calculated to leading order only, correspond to taking $C_s = 0$ and $C_r = AZe^2/BJ$, where $A$ is the mass number and $J$ is the symmetry energy coefficient ($\approx 33$ MeV). A more accurate treatment, following from a consistent application of the Droplet Model, leads to

$$C_r = (AZe^2/BJ) \left[ \frac{1}{J} + \frac{6L}{JK} I + \frac{15}{80} A^{-1/3} \right], \quad (3)$$

$$C_s = (3NZ/A)\bar{\epsilon} = (2NZ/A)(I - \bar{\delta})R_0, \quad (4)$$

where
In the above, $I$ is the overall relative neutron excess, $(N-Z)/A$, $\bar{\delta}$ is the average relative neutron excess in the bulk [i.e. the average of $(n-p)/(n+p)$ in the bulk], whose Droplet Model equilibrium value is given by eq.(5), and $\bar{\xi}$ is the average value of the neutron skin thickness, related to $I$ and $\bar{\delta}$ by the 'geometrical' expression

$$\bar{\xi} = \frac{2}{3}(I - \bar{\delta})R_0$$ \hspace{1cm} (6)

The three Droplet Model coefficients appearing in eq.(3) are the compressibility coefficient $K$ ($\approx 240$ MeV), the density symmetry coefficient $L$ ($\approx 0$-100 MeV) and the effective neutron-skin stiffness coefficient $Q$ ($\approx 30$ MeV). In eq.(5), $c_1$ is the Coulomb energy coefficient, given by $c_1 = (3/5)e^2/r_0$, where $r_0 = R_0/A^{1/3}$.

We note that, compared to the older estimates of the dipole moment, eqs.(3),(4) introduce three new contributions: the neutron skin term (eq.(4)), a neutron-excess correction (the term in eq.(3) proportional to $I$) and the last term in eq.(3), which is a charge-redistribution contribution associated with the non-uniformity of the neutron skin.

In order to illustrate the relative magnitudes of the various contributions, we present below numerical results based on using the following set of recent Droplet Model parameters (Sec. 4 below, and ref. 3): $J = 32.5$ MeV, $K = 240$ MeV, $L = 0$, $Q = 29.4$ MeV, $r_0 = 1.16$ fm ($c_1 = 0.744816$ MeV). We use eqs.(1)-(5) to calculate the
NEW DROPLET MODEL DEVELOPMENTS

Macroscopic dipole moments for $^{222}\text{Th}$ and $^{226}\text{Ra}$, for which calculated ground-state deformations are given in ref. 11 as $\beta_2 = 0.114$, $\beta_3 = 0.096$, $\beta_4 = 0.0678$ and $\beta_2 = 0.159$, $\beta_3 = 0.083$, $\beta_4 = 0.0872$, respectively. (The deformation parameters $\beta_2$ are related to $\alpha_2$ by $\alpha_2 = \sqrt{(2l + 1)/4\pi} \beta_2$). The result of this calculation is as follows:

$$d = 0.1564 + 0.0 + 0.0548 - 0.1880 = 0.0232 \text{ fm} \quad (7)$$

for $^{222}\text{Th}$, and

$$d = 0.1832 + 0.0 + 0.0624 - 0.2620 = -0.0164 \text{ fm} \quad (8)$$

for $^{226}\text{Ra}$.

The first three contributions to $d$ in these equations correspond to the three terms in eq.(3) and the last (negative) contribution corresponds to the neutron-skin effect represented by eq.(4).

The most striking feature of these results is the importance of the neutron-skin contribution which, in the above examples, tends to wipe out the redistribution contribution, leaving a final dipole moment several times smaller than would be given by the simplest redistribution calculation (i.e. by the first term in eq.(3)).

Without being able at this time to make a closer analysis of the relation of the macroscopic theory to the experimental determinations of the dipole moments of nuclei, we hope that the relatively accurate Droplet Model expression for the macroscopic part, eq.(1), will be of help in improving our understanding of this aspect of
nuclear structure.

3. **BULK COMPRESSION DUE TO SURFACE TENSION**

A number of recent studies have been devoted to the comparison between density distributions predicted by the Droplet Model of atomic nuclei and those predicted by Hartree-Fock calculations. Some of these studies raised questions about the validity of the Droplet Model approach for treating the neutron skin in neutron-rich nuclei and, in particular, about an elementary prediction of the Droplet Model concerning the squeezing of nuclei by the surface tension. While existing Hartree-Fock calculations were not sufficiently comprehensive to be able to settle these questions, certain features of the numerical results raised concerns over whether or not the Droplet Model was correctly formulated. The relation of the Droplet Model to Thomas-Fermi (rather than Hartree-Fock) calculations had been thoroughly investigated in the original Droplet Model paper and perfect agreement had been found as regards the neutron skin as well as the surface tension squeezing in the appropriate limit of sufficiently large nuclei, in which the Droplet Model should formally be valid. However, two questions still remained. First, does the change from a Thomas-Fermi to a Hartree-Fock treatment, in addition to bringing in the expected oscillations in nuclear properties associated with shell effects, also modify in some unsuspected way the shell-averaged behaviour, thus invalidating the Droplet Model predictions of average nuclear properties? Second, even if the Droplet Model predictions were found to be formally valid for sufficiently large hypothetical nuclei,
are they quantitatively useful for actual nuclei throughout the periodic table? Again, comparisons with Thomas-Fermi calculations in ref. 21 suggested that this might be the case but, as regards the question of the surface tension squeezing, there was already a hint of potentially serious quantitative limitations in Figure 30 of that reference, which showed that the Droplet Model prediction of a squeezing that increased monotonically with increasing surface to volume ratio ceased to be valid below about mass number $A \approx 45$. The Thomas-Fermi calculations showed that for lighter nuclei the central density of the model nucleus decreased with decreasing $A$, a behaviour qualitatively different from the Droplet Model prediction.

The Droplet Model prediction for the fractional increase in the density inside a nucleus may be found in ref. 22. We recall that the expression for the simplified situation to be studied here corresponding to a fictitious, spherical, uncharged nucleus with equal numbers of neutrons and protons ($N = Z$) is

$$\frac{\Delta \rho}{\rho_0} = \frac{6a_z}{(6a_z/K)A^{1/3}}$$  \hspace{1cm} (9)

In order to test eq.(9) we performed two sets of Hartree-Fock calculations, using two types of Skyrme interactions corresponding to two values of the incompressibility coefficient: $K = 355.6$ MeV for the Skyrme force S-III and $K = 216.6$ MeV for the Skyrme force SkM. In each case we determined the self-consistent Hartree-Fock density distributions for all closed-shell spherical nuclei with $N = Z$ and mass number $A$ from 16 to 3112. (There was no spin-orbit force, so the shell
closures do not correspond to those for actual nuclei.)

The resulting Hartree-Fock density distributions exhibit the usual radial ripples associated with quantal effects, so the extraction of a bulk density to be compared with eq.(9) is not a trivial matter. Some kind of smoothing of the rippled distributions is necessary. The method we adopted was to make a least-squares fit of a smooth distribution to the radial Hartree-Fock density function, weighted with $r^2$, and to use the central value of the smooth density as a representation of the bulk density of the Hartree-Fock distribution.

Figure 1 shows the values of $(\Delta \rho/\rho_0)$ obtained in this way, plotted as a function of $A^{-1/3}$, where $\rho_C$ is the value of $\rho$ at the center, i.e. $\rho_C = \rho(r = 0)$. The two Skyrme interactions lead to qualitatively similar results. Two features are immediately apparent: most nuclei are squeezed (their bulk densities exceed nuclear matter density by several percent) but the squeezing shows very large shell-effect fluctuations.

As regards the absolute values of the fluctuations in Figures 1a, b, we would expect them to be larger than in the actual nuclei. First, the spin-orbit coupling, Coulomb effect and neutron excess would reduce the degree of degeneracy of the single-particle eigenvalues in actual nuclei and thus reduce the shell effect. Second, there are indications that Hartree-Fock calculations tend to exaggerate the ripples in the density distributions—the reason may have to do with the neglect of residual nucleonic interactions (such as pairing) or other idealizations of the Hartree-Fock theory.

Even with the probably exaggerated fluctuations of the
FIGURE 1a   The fractional deviation of the bulk density extracted from Hartree-Fock calculations using the force S3 is plotted against $A^{-1/3}$ for nuclei with $N = Z$ and with mass numbers from 16 to 3112. The straight line represents the lowest order Droplet Model prediction, eq. (21), the dot-dash curve the higher-order approximation, eq. (22), and the dashed curve the Thomas-Fermi result.

In idealized Hartree-Fock calculations in Figs. 1a and 1b it is possible to discern systematic trends, which may be compared with the Droplet Model predictions, given by the straight line. (In eq.(9) values of $a_2$ and $K$ appropriate to the Skyrme model in question were used. For very large systems ($A^{-1/3} < 0.15$ i.e. $A > 300$) there is clear
indication that the Hartree-Fock bulk densities are converging towards the nuclear matter value (i.e. \( \Delta \rho \to 0 \)). This removes the misgivings one might have had (by looking only at the points for \( A < 300 \)) that even this elementary expectation was not borne out by the numerical calculations. The prediction of the Droplet Model is, roughly speaking, consistent with the trend of the Hartree-Fock calculations for \( A^{-1/3} < 0.15 \). (One cannot be very quantitative about this in view of the large fluctuations in the calculated points as well as the possible ambiguities associated with the extraction of bulk...
NEW DROPLET MODEL DEVELOPMENTS

values from the Hartree-Fock densities.) For lighter nuclei, one can discern, despite the large fluctuations, a tendency for the average of $\Delta \rho/\rho_0$ to decrease, contrary to the Droplet Model prediction. We had already noted such a trend in the Thomas-Fermi calculations in ref. 21.

Our analysis (in ref. 2) suggests that the underlying reason for the down-turn is the breakdown of the leptodermous assumption, i.e. the fact that the exponential tail of the inner part of the surface diffuseness is beginning to reach into the center of the system. It follows that, in order to have a model which is capable of describing the reversal of the bulk squeezing of nuclei below some mass number like 45 (if $K = 295$ MeV) or 100 (if $K = 217$ MeV), it is essential to go beyond a polynomial Droplet Model and include, at some stage, exponential terms of the type $\exp(-cA^{1/3})$, with a value of $c$ such that a downturn in the central density will occur around $A \approx 50-100$.

Non-analytic, exponential terms appear explicitly in folding-type calculations, where a finite-range interaction is folded into a generating density distribution. Exponential terms can also be exhibited in Thomas-Fermi calculations for which explicit solutions can be written down.

In the next section we will discuss an attempt which was made to include an adjustable exponential term in a semi-empirical nuclear mass formula, based on the "Finite Range Droplet Model." The new term in the binding energy was taken to be

$$\Delta E = -CAe^{-YA^{1/3}}$$  \hspace{1cm} (10)
where C and \( \gamma \) were treated as adjustable parameters and \( \epsilon \) (proportional to \( \Delta \rho / \rho \)) was allowed to assume its optimum value. A fit of the new formula to nuclear ground state masses and fission barriers demonstrated the practical utility of the exponential term.

As a concluding remark we would like to suggest that future efforts in the macroscopic descriptions of nuclear masses and densities should concentrate on a better understanding of the exponential, non-analytic terms, which begin to dominate for small (holodermous) systems. We hope that the present study, in addition to removing certain misgivings concerning the Droplet Model by clarifying its limitations, will contribute to a better understanding of these terms.

4. FINITE RANGE DROPLET MODEL

In the previous section we mentioned the possibility of inserting an empirical exponential term, given in eq.(10), into the Droplet Model mass formula. This proposal was carried out and is described in detail in ref. 3. The Droplet Model coefficients that are arrived at by fitting such an expression to measured masses are,

\[
\begin{align*}
  a_1 &= 16.2663 \text{ MeV} \\
  r_0 &= 1.16 \text{ fm} \\
  a_2 &= 23.0 \text{ MeV} \\
  c_1 &= \frac{3}{5} \left( \epsilon^2 / r_0 \right) \\
  a_0 &= 2.5 \text{ MeV} \\
  Q &= 29.4 \text{ MeV} \\
  J &= 32.5 \text{ MeV} \\
  C &= 230 \text{ MeV} \\
  K &= 240 \text{ MeV} \\
  a_3 &= L = M = 0 \\
  \gamma &= 1.27
\end{align*}
\]
NEW DROPLET MODEL DEVELOPMENTS

The data set to which our fitting procedure was applied consisted of 1323 masses (with \( N \) and \( Z \) = 8 or greater, and experimental errors less than 1 MeV) from the 1977 compilation of Wapstra and Bos\(^{24} \) supplemented by 165 additional masses from ref. 25. The set of 28 fission barriers was the same as the one used earlier by Möller and Nix\(^{8} \).

The r.m.s. deviation that we obtained was 0.676 MeV for the masses and 1.135 MeV for the fission barriers. The upper part of Figure 2 compares the measured and calculated deviations from the smooth part of the mass formula (the

![Graph

FIGURE 2  Comparison of measured and calculated ground-state shell effects for 1488 nuclides.
shell effect). The bottom part of Figure 2 displays the difference between the two, which is also the difference between calculated and measured atomic masses. There is no systematic long-range structure (either along or across the valley of beta-stability) as far as we can tell. The key to the substantially improved results we have obtained here seems to be the empirical, exponential term of eq.(10). The quantity plotted in Figure 3 versus $A^{-1/3}$ is $(\Delta \rho/\rho_0)_{\text{bulk}}$, which is the fractional deviation of the central density of a nucleus from the nuclear matter...
NEW DROPLET MODEL DEVELOPMENTS

value. For the idealized case of $N = Z$ nuclei without Coulomb energy the FRDM expression for this quantity is,

$$(\Delta \rho/\rho_o)_\text{bulk} = 6(a_2/K)A^{-1/3} - 3(C/K)e^{-\gamma A^{1/3}}$$  \hspace{1cm}(12)

The solid line in the figure is the old DM prediction obtained by keeping only the first term. The dashed line illustrates the dramatic effect which is produced by including the second term in eq.(12). The behavior of this complete expression corresponds very closely to that found in earlier Thomas-Fermi calculations. It also corresponds quite closely to the behavior we have noted in the previous section in studies of Hartree-Fock calculations. This is all the more remarkable when we recall that the coefficients of this new phenomenological term were determined solely from a least squares fit to masses and fission barriers. No considerations regarding density distributions governed their determination.

We find that the quantity $L$ is approximately zero (and not well determined). We also find that the value of $Q$ has increased substantially over earlier determinations. The increase in $Q$ and reduction in $L$ combine to leave nearly unchanged the predictions of the model for isotope shifts in nuclear charge radii.

It is interesting to note that the further developments of the Droplet Model that are described here are bringing the values of the coefficients more in line with those associated with Skyrme force Hartree-Fock calculations.
5. FINAL REMARKS

The development of nuclear mass formulae since the thirties has been characterized by a dramatic improvement in the treatment of shell effects in the sixties and by a more gradual improvement in the smooth part of the equations. Very roughly speaking, the standard Liquid Drop formula considered energy terms of order $A$ and $A^{2/3}$, the Droplet Model extended the expansion to order $A^{1/3}$. In the past few years the folding model has also begun to focus attention on the existence of an exponential, non-analytic term in $A^{-1/3}$, inaccessible to a Droplet Model type of expansion in this parameter. The development described in the present paper, based on including an adjustable exponential term of this type, demonstrates the practical utility of such a term and its relation to the problem of surface-tension squeezing of light nuclei. It seems to us that the limit of a useful Droplet Model type of power expansion in $A^{-1/3}$ is probably reached around $A^0$, and that future efforts should concentrate on a better understanding of the "exponential," non-analytic term. This term focuses attention on a specific feature of a light system, for which the range of the interaction begins to be comparable with its size. This is the opposite extreme from the limit underlying the standard (leptodermous) treatment of saturating systems. Such non-analytic terms might be described as dealing with "desaturating" effects, which begin to dominate for small (holodermous) systems. A general discussion of such terms and their incorporation in mass formulae is an outstanding problem for the future.
NEW DROPLET MODEL DEVELOPMENTS

ACKNOWLEDGEMENTS

This work was supported by the Director, Office of Energy Research, Division of Nuclear Physics of the Office of High Energy and Nuclear Physics of the U.S. Department of Energy under Contract DE-AC03-76SF00098.

REFERENCES

†Permanent address: Departmento de Fisica, Facultad de Ciencias Exactas y Naturales, universidad de Buenos Aires, 1428 Buenos Aires, Argentina.

‡Permanent address: Department of Mathematical Physics, Box 725 S-22007 Lund, Sweden

1. C.O. Dorsa, W.D. Myers and W.J. Swiatecki, Lawrence Berkeley Laboratory Preprint, LBL-19873 (to be published in Nuclear Physics)
15. W.J. Swiatecki, Phys. Rev. 83 (1951) 178; J. de Physique, suppl. nr. 8-9, 33 (1972) C5-45
19. M. Brack et al., Proc. 4th Int. Conf. on nuclei far from stability, P.G. Hansen and O.B. Nielsen, eds. CERN 81-09, Geneva 1981
This report was done with support from the Department of Energy. Any conclusions or opinions expressed in this report represent solely those of the author(s) and not necessarily those of The Regents of the University of California, the Lawrence Berkeley Laboratory or the Department of Energy.

Reference to a company or product name does not imply approval or recommendation of the product by the University of California or the U.S. Department of Energy to the exclusion of others that may be suitable.